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A SIMPLE SCREW THREAD MODEL FOR USE IN FINITE ELEMENT STRESS ANALYSIS

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JULY 1989

U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A technique for modelling screw threads, such as those found on artillery projectiles, has been developed. The model employs a matrix of gap elements which are easier to use and require less computation time than the current method of modelling actual threads with material elements. A comparison of this new method to the current method illustrates that there is no trandeoff of accuracy.

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I. INTRODUCTION

Structural analysis of projectiles and other ballistic components often require the modelling of screw threads. Typically, many finite elements are required in the immediate vicinity of the joint to accurately define and model a thread. In addition, reconciling the effect of dimensional tolerances of threads is not a simple effort. For example, if an analyst were required to perform a complete analysis of a threaded region, including tolerance considerations, at least four iterations would be required. These would include the mating of large and small pitch diameter male threads (within the tolerance range) with both large and small female threads (also within tolerances).

A new technique for modelling threads was developed during a study of ogive failures of the M483 155-mm artillery projectile to simulate the coupling of the aluminum ogive to the steel body. The technique employs a simple matrix of gap elements to model thread behavior as opposed to the labor-intensive method of representing threads with a finite element mesh. Substantial time and computer memory savings can be realized by employing this technique with no penalty in accuracy.

These new "thread elements" greatly simplified the effort. Otherwise, it would have been necessary to use very small elements to accurately grid each of the threads in the joint region. For a dynamic analysis in which stress waves were a consideration, this would have required a very small time step which is proportional to element size in this case. The combination of small time steps and numerous elements would generate output data that may exceed the limits of the computer storage device. Also, the run times would be prohibitively long. For example, it requires one thread element (set of three gap elements) to model one thread pair and at least eight material elements to realistically mesh a single male or female thread. Also, slide lines would have to be included at the closing flanks which is built into the thread elements. The new technique is also useful in the study of thread fit and tolerances. The thread elements can be used to model these effects on the behavior of the overall structure by adjusting the "modulus" in the axial direction. This modulus might be determined from an experimental pull test on a thread specimen where a stress-strain curve can be developed for the thread "material". The modulus determined from such a test can then be input directly as a material property for the gap elements used to model threads. A set of three such gap elements are required to construct a standard thread element. The approach here has many benefits in analyzing coupled bodies. However, if the details of the stress and strain state in the vicinity of the threads must be studied, then there is no recourse other than the construction of a detailed local model.

II. METHODOLOGY

The ANSYS[1] finite element program is used for all analyses included in this report. However, any general finite element code with gap element capability could be used. The user must know a priori that small deformations are expected as there is no provision for releasing axial constraints should the threads completely decouple radially. The threaded joint used to develop this technique is found on the M483 155-mm artillery projectile between the steel body and aluminum ogive. An ongoing study of ogive failures provided the opportunity for the development of this technique. The original study of these failures was performed by Southwest Research Institute[2] whose finite element analysis includes gridding of the threaded region. Their analysis provides the "geometry" technique as a basis of comparison to the present "material model" technique for representing thread behavior.

A threaded joint has basically four possible responses to any given load. It can be sheared in tension or compression in response to a tensile or compressive axial load respectively. Also, the threads can either compress together or separate in response to a compressive or tensile radial load. The joint studied in this case has a buttress thread since the expected axial load can only act in one direction. A section of rotation of the threaded region is illustrated in Figure 1. There is virtually no chance that non-load bearing flanks will meet in this type of thread series.

A schematic representation of a buttress thread is shown in Figure 2 along with its finite element model. The flank gap element angle, o, relative to the axis is defined to be the same as the actual flank angle and there is one radial gap element for each thread.

A gap element has only two properties: a stiffness modulus and coefficient of friction. The modulus of the closed gap elements, E_{eq}, is calculated by adding reciprocally the moduli of the two mating materials (the same as adding two spring constants in series, $E_{eq} = E_1E_2/(E_1 + E_2)$). Since each "spring" is only half the length typically used in this well-known equation, the modulus must be multiplied by 2. Thus, a gap element between aluminum and steel would have a

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[2] Cox, P.A., et al, "A Root Cause Analysis of the M483A1 Ogive," Southwest Research Institute, April 1987.

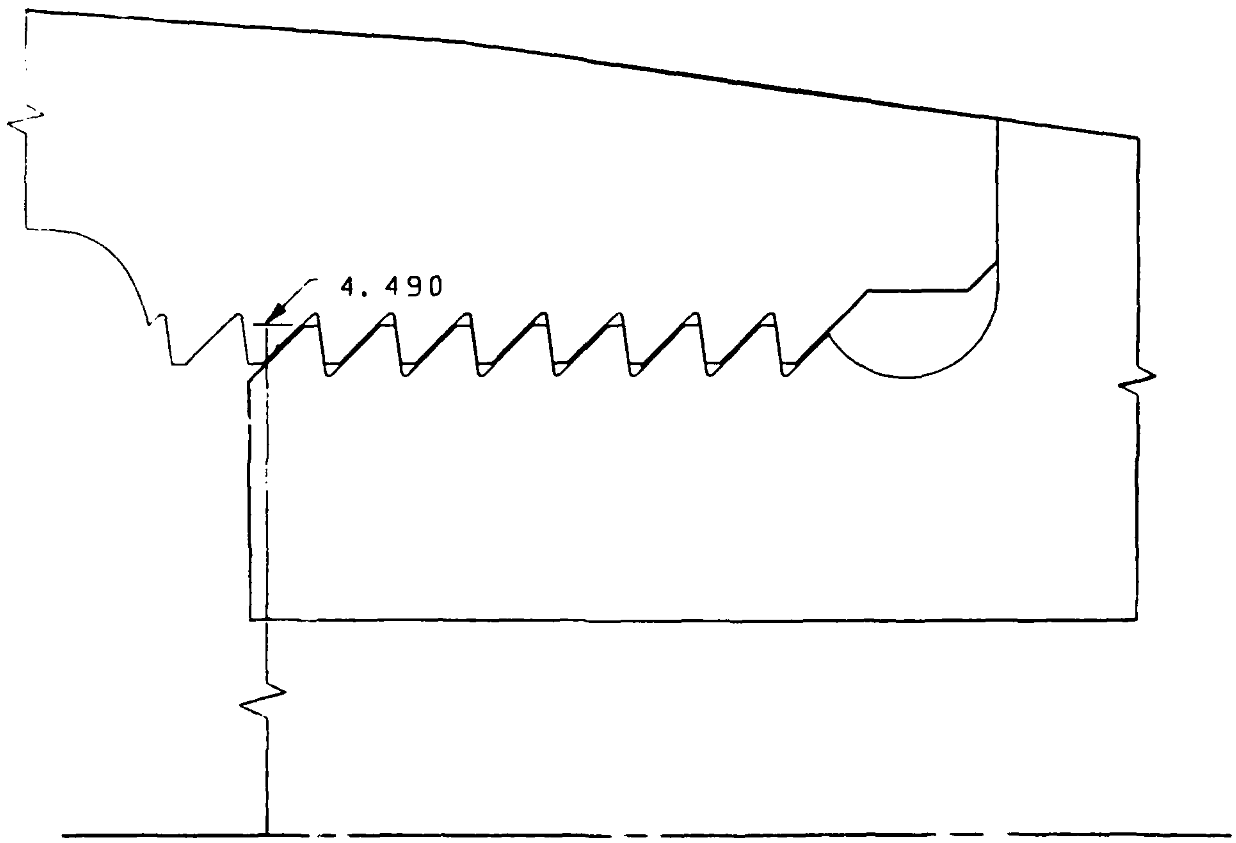

Figure 1. Section of Rotation of the Threaded Joint.

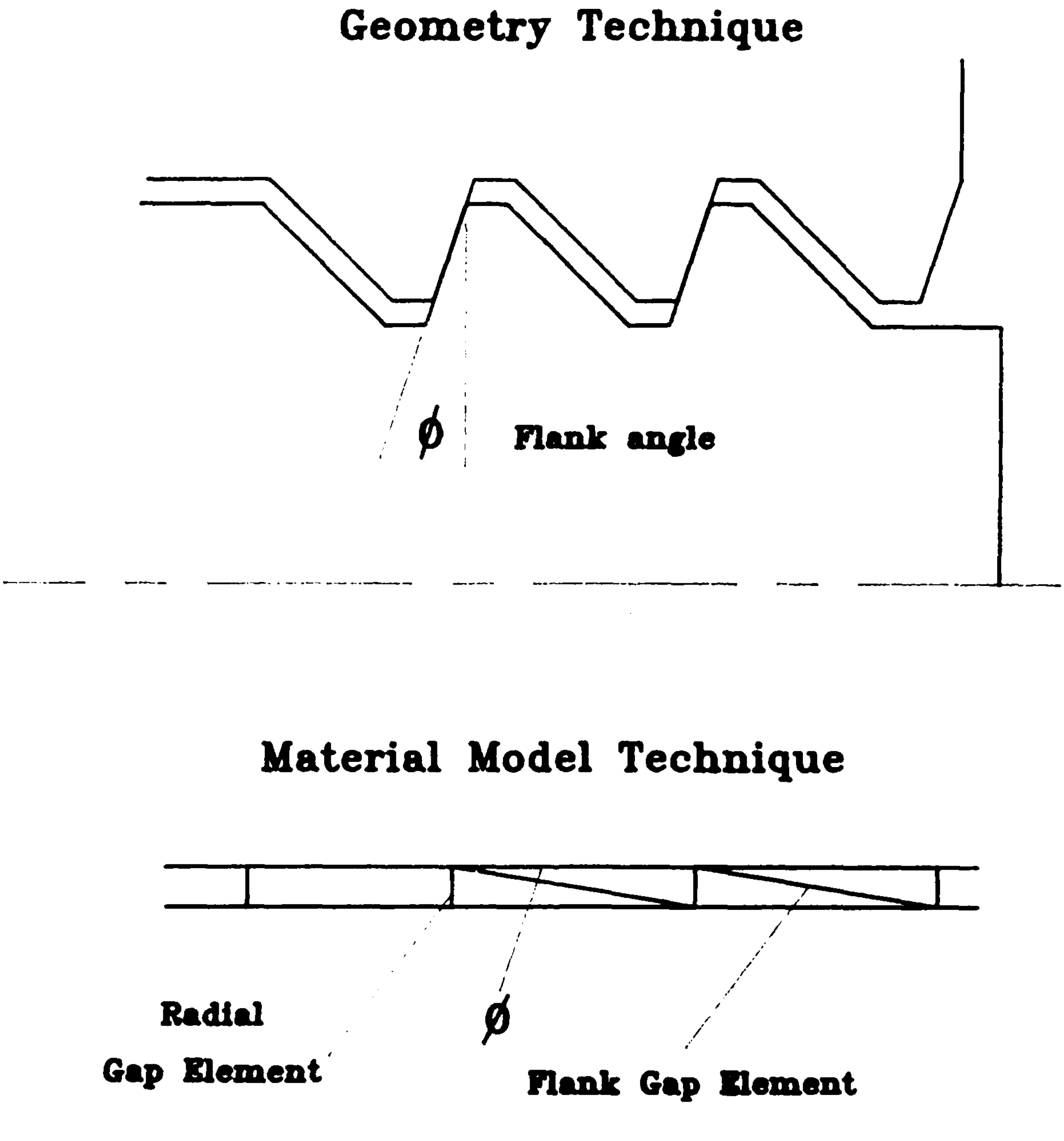

Figure 2. Schematic Representation of a Buttress Thread and its Finite Element Model.

modulus of 15 Mpsi. Sliding is permitted after closure, and a coefficient of friction can be selected from a handbook or determined from other means.

Two finite element models of the threaded region are illustrated for comparison in Figure 3. The actual threads are modeled in the grid on the left and thread elements are depicted in the grid on the right. The dotted line on the left model represents the surface where internal pressure of 12,000 psi is applied.

III. RESULTS

One of the responses of the joint which can be measured is the separation of the closing faces. This gives an indication of the overall strength of the threads. The Southwest Research analysis predicts that the butt joint between the body and ogive will open .009 inch at peak load while the thread element model predicts a .010 inch separation indicating an agreement to within ten percent.

The gap separation indicated on the ANSYS color stress plot in Figure 4 compares favorably (within ten percent) with the plot above it of gap separation versus time from SRI. As far as stress levels in thread roots and crests are concerned the thread element model offers no information.

IV. DISCUSSION

The thread element model represents a method by which the analyst can more easily develop the finite element grid for jointed structures. A simple model is more easily understood both by the analyst and those to whom the results are conveyed. Also, the chances of modelling errors are reduced with less complex models.

In addition to model simplicity, less time is required for grid development and computer computations, often a concern with small networks. Also, fewer elements mean less computer storage space is needed. In some cases, the time and memory reductions can be significant. This is best illustrated when analyzing a structure for stress waves or vibration[3].

[3] Bender, J.M. "Stress Waves Through Joints of Artillery Projectiles," Baliistic Research Laboratory-TR-2980, Jan 1989.

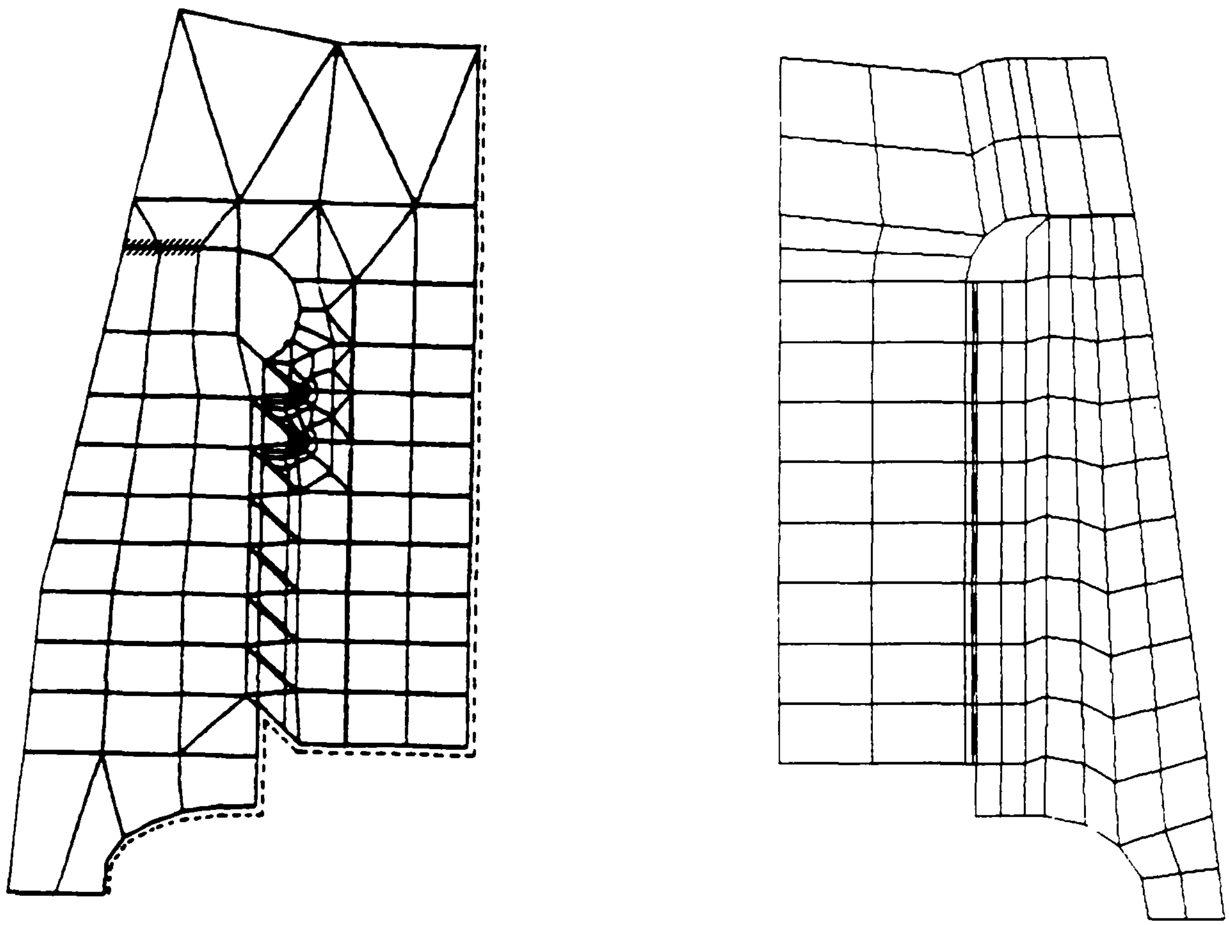

Figure 3. Comparison of Finite Element Models.

When performing a finite element dynamic[3] analysis, the time step is a function of the element size[3]. The element size for a thread element is the distance between two threads. In contrast, the geometry method may require the use of many elements to span a thread. Consequently, the time step must be much smaller to accomodate the smaller elements for accurate modelling of dynamic effects such as vibration and stress waves. The disadvantage with smaller time steps is that many more iterations are required during the time span of the analysis. For example, if element size is reduced to one fourth of its original size, the time step is likewise reduced. This means it will take four times the number of time steps to span the duration of the analysis since each time step represents one computation of strains. Almost always, this means a similar increase in computer time and memory storage.

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[4] Kohnke, P.C., ANSYS Theoretical Manual, Swanson Analysis Systems, Inc., 1983.

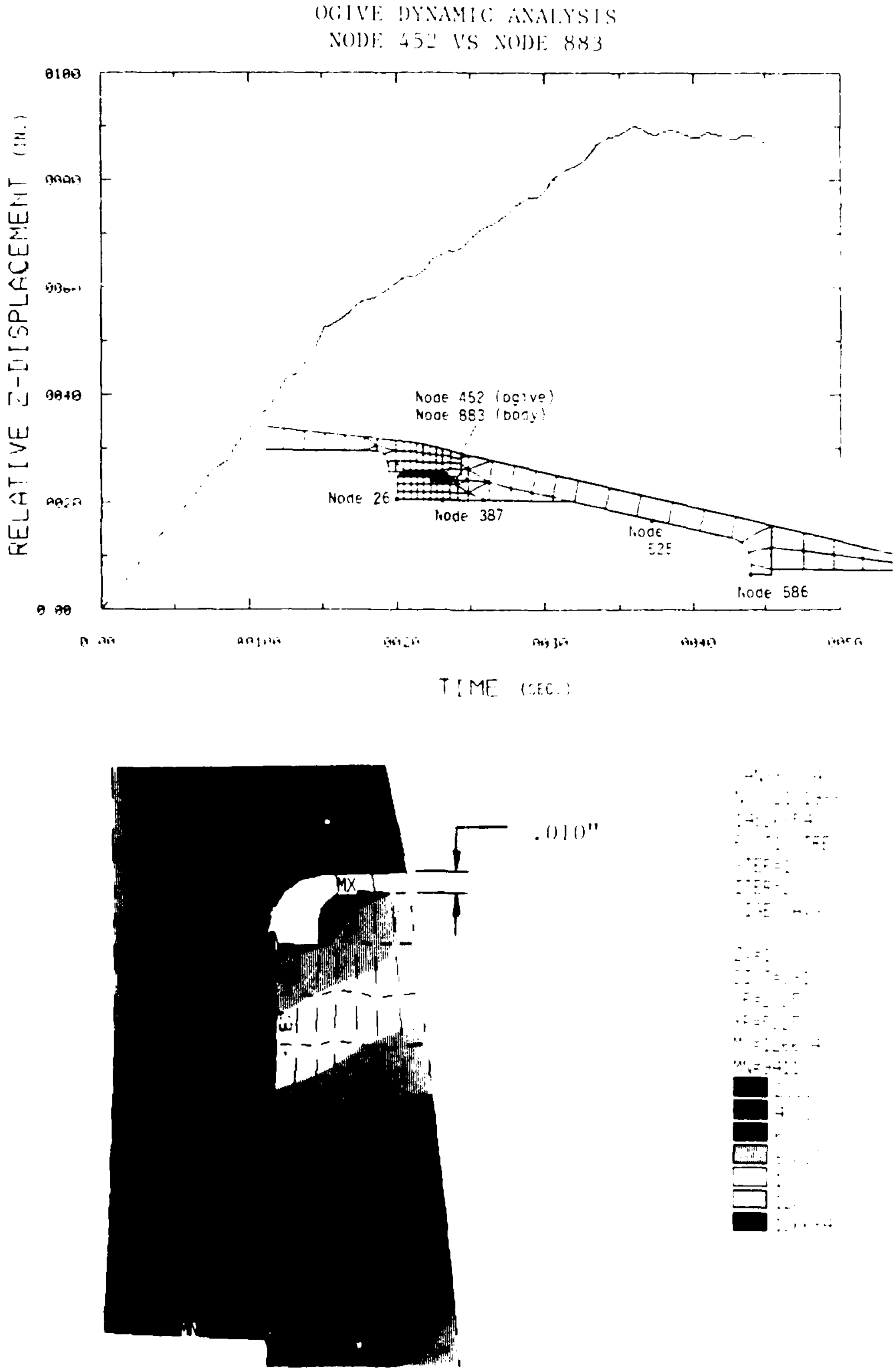

Figure 4. Comparison of Models' Responses.

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[5] Timoshenko, S.P., and Goodier, J.N., <u>Theory of Elasticity</u>, Prentice-Hall, 1970.

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